

SECTION 4

POTENTIAL DANGER TO HUMAN HEALTH AND THE ENVIRONMENT

This section assesses the potential danger to human health and the environment associated with wastes generated by the mining industry. It identifies the hazardous chemical and physical characteristics of these wastes, estimates the amount and type of mining waste possessing these characteristics, describes mining waste damage case studies compiled by EPA, and discusses the effectiveness of mining waste management systems.

In this section, EPA is responding to the requirements of Sections 8002(f) and (p) of RCRA for analyses of the "potential dangers to human health and the environment from surface runoff of leachate," the "potential danger, if any, to human health and the environment from the disposal and reuse" of mining waste, and "documented cases in which danger to human health or the environment has been proved." Over a period of years, EPA has conducted these analyses with the support of consulting firms and individual experts.

The studies sponsored by EPA involved waste sampling at 86 mines in 22 states; chemical analyses of solid and liquid samples (and leachates from the solid samples); and monitoring of ground water at seven of eight representative sites (and surface water of five of the sites).

Reports on mining industry damage cases were obtained from state files and from information in EPA's files on sites on the National Priorities List for Superfund cleanup. The damage case analysis focused on the range and severity of contamination problems associated with mine and mill waste disposal at active, inactive, abandoned, and Superfund sites.

EPA is currently analyzing the amounts and rates of toxic releases from mine and mill wastes. This is an essential prerequisite to studies on exposures and effects, and is required for any quantification of risks to human health and the environment posed by these wastes.

4.1 WASTE CHARACTERISTICS CONSIDERED

Mining wastes may contain constituents, such as heavy metals, other toxic elements, radionuclides, cyanide compounds, and asbestos, that may be dangerous to human health and the environment. In addition, some mine wastes are corrosive (acidic) and others have a high potential for forming acid.

Table 4-1 presents the waste characteristics evaluated for this report, the criteria used to determine whether or not mining wastes have these characteristics, and the rationale for choosing these criteria. As the table indicates, EPA evaluated two general categories of waste characteristics for this report: RCRA Subtitle C Hazardous Waste Characteristics and Other Potentially Hazardous Characteristics. The following sections discuss the waste characteristics evaluated, the sampling methodology, and the sampling results obtained by EPA at selected mine sites.

To evaluate the hazardous characteristics of mining waste for this report, EPA's Office of Solid Waste (OSW) subdivided mining industry segments into the following mining region-commodity categories:

- New Mexico Uranium;
 - * Wyoming Uranium;
- Other Uranium;
 - *Florida Phosphate;
- Idaho Phosphate;
- Other Phosphate;

Table 4-1 Waste Characteristics, Hazard Criteria, and Bases for Criteria Used to Assess the Hazard Potential of Mining and Beneficiation Wastes

Waste characteristic	Hazard criterion	Basis for criterion
<u>RCRA Subtitle C Hazardous Waste Characteristics</u>		
- Corrosivity	pH <2.0 or pH >12.5	40 CFR 261.22
- EP Toxicity	Metals in EP Extract:	40 CFR 261.24
	Mercury >0.2 mg/l	(100 times
	Cadmium >1.0 mg/l	National Interim
	Selenium >1.0 mg/l	Primary Drinking
	Silver >5.0 mg/l	Water Standards
	Arsenic >5.0 mg/l	for Metals)
	Chromium >5.0 mg/l	
	Lead >5.0 mg/l	
	Barium >100.0 mg/l	
- Ignitability	(See definition used in 40 CFR 261.21)	40 CFR 261.21
- Reactivity	(See definition used in 40 CFR 261.23)	40 CFR 261.23
<u>Other Potentially Hazardous Characteristics</u>		
- Cyanide	Cyanide >2 mg/l >10 mg/l >20 mg/l	(10, 50, and 100 times the Ambient Water Quality criterion for protection of human health, respectively)
- Radioactivity	Ra 226 >5 pCi/gm Ra 226 >20 pCi/gm	40 CFR Part 192 Derived from 40 CFR Part 192
- Asbestos	Asbestos content >1% by wt.	40 CFR Part 61
- Acid formation potential	Presence of metal sulfides and absence of carbonate minerals by acid drainage	Danger posed to the environment

Source: Compiled by EPA, OSW staff, 1985.

Southwestern Copper;

Other Copper;

Western Lead/Zinc;

Eastern Lead/Zinc;

Missouri Lead/Zinc;

Molybdenum;

•Nevada Gold/Silver;

Other Gold/Silver;

Taconite/Iron; and

•Tungsten.

EPA sampled at least one mine and mill in each of these categories for this study.¹ EPA then augmented this sample set by taking samples from operations (e.g., heap and dump leach operations) and industries (e.g., beryllium and rare earth metals) either not covered at all, or not sufficiently covered in the first sample set.² These results were then supplemented with data from a study performed for EPA's Effluent Guidelines Division (now the Industrial Technology Division) on the following mining industry segments: antimony, bauxite (aluminum), mercury, nickel, titanlure, tungsten, and vanadium.³ EPA's Industrial Environmental Research Laboratory performed the analyses of waste samples from mines in the asbestos mining industry. Generally, EPA sampled the full range of waste types (e.g., fresh tailings, mine water pond liquid and settled solids, tailings liquid and settled solids, pregnant and spent leach liquor (process liquors that may be characteristic of seepage from leach operations), and tailings dike material) produced by mining and beneficiation operations in these segments. The Agency also took additional samples of those wastes believed to be most likely to present a hazard to human health and the environment (e.g., heap and dump

leach wastes). For this reason, the percentage of samples having hazardous or potentially hazardous characteristics is probably greater than would have been the case if a completely random sampling strategy had been used. However, the Agency excluded all results from samples that were believed to be either invalid or duplicative.

EPA's Office of Solid Waste planned the original sampling and analysis effort in 1979-1980 and, with the cooperation of the Office of Research and Development, took samples between 1979 and 1984. To show the scope of EPA's mining waste sampling and analysis effort, Table 4-2 presents 1980 figures for the number of active mines, the number of mines sampled, and the percent of mines sampled. Data are presented for 1980, because this was the year in which the sampling effort was planned and initiated. This table shows that EPA sampled 13 percent of all metal mines and 31 percent of all asbestos and phosphate mines active in 1980. Figure 4-1 is a map showing the locations of the mines EPA sampled.

4.1.1.1 RCRA Subtitle C Hazardous Waste Characteristics

Solid wastes are defined as hazardous under regulations implementing Subtitle C of RCRA if they exhibit any of four general characteristics: ignitability, corrosivity, reactivity, or EP toxicity. They are also considered hazardous if they are listed as hazardous in 40 CFR 261.31-261.33. Wastes may be listed under RCRA if the Administrator of EPA determines that the wastes meet one of the criteria in 40 CFR 261.11. The Administrator must indicate whether the wastes are ignitable, corrosive, reactive, EP toxic, acutely hazardous, or toxic (40 CFR 261.30). Since Congress has, at least temporarily, excluded mining wastes from regulation under Subtitle C of RCRA, EPA's current lists of hazardous wastes do not include wastes from mining and beneficiation processes.

Table 4-2 Scope of EPA's Mine Waste Sampling
and Analysis Effort

Mining industry segment	Number of active mines in sector, 1980 ^a	Number of active mines sampled	Percent of active mines sampled
<u>Metals:</u>			
Antimony	1	1	100
Bauxite (Aluminum) ^b	2	1	50
Beryllium	1	1	100
Copper	39	13	33
Gold ^c	44	6	14
Iron	35	5	14
Lead	33	4	12
Mercury	4	1	25
Molybdenum	11	3	27
Nickel	1	1	100
Rare earth metals	2	1	50
Silver	43	6	14
Titanium	5	2	40
Tungsten	29	1	3

Table 4-2 (continued)

Mining industry segment	Number of active mines in sector, 1980 ^a	Number of active mines sampled	Percent of active mines sampled
Uranium	265	17	6
Vanadium	1	1	100
Zinc	20	7	35
Subtotal	536	71	13
<u>Nonmetal s:</u>			
Asbestos	4	2	50
Phosphate	44	13	30
Subtotal	48	15	31
TOTAL	584	86	15

a Estimated by Bureau of Mines 1981 (BOM 1982).

b Although the BOM lists 10 active mines, there were only two operations supplying bauxite for aluminum reduction. The other mines are supplying bauxite for other uses.

c Excludes placer mines.

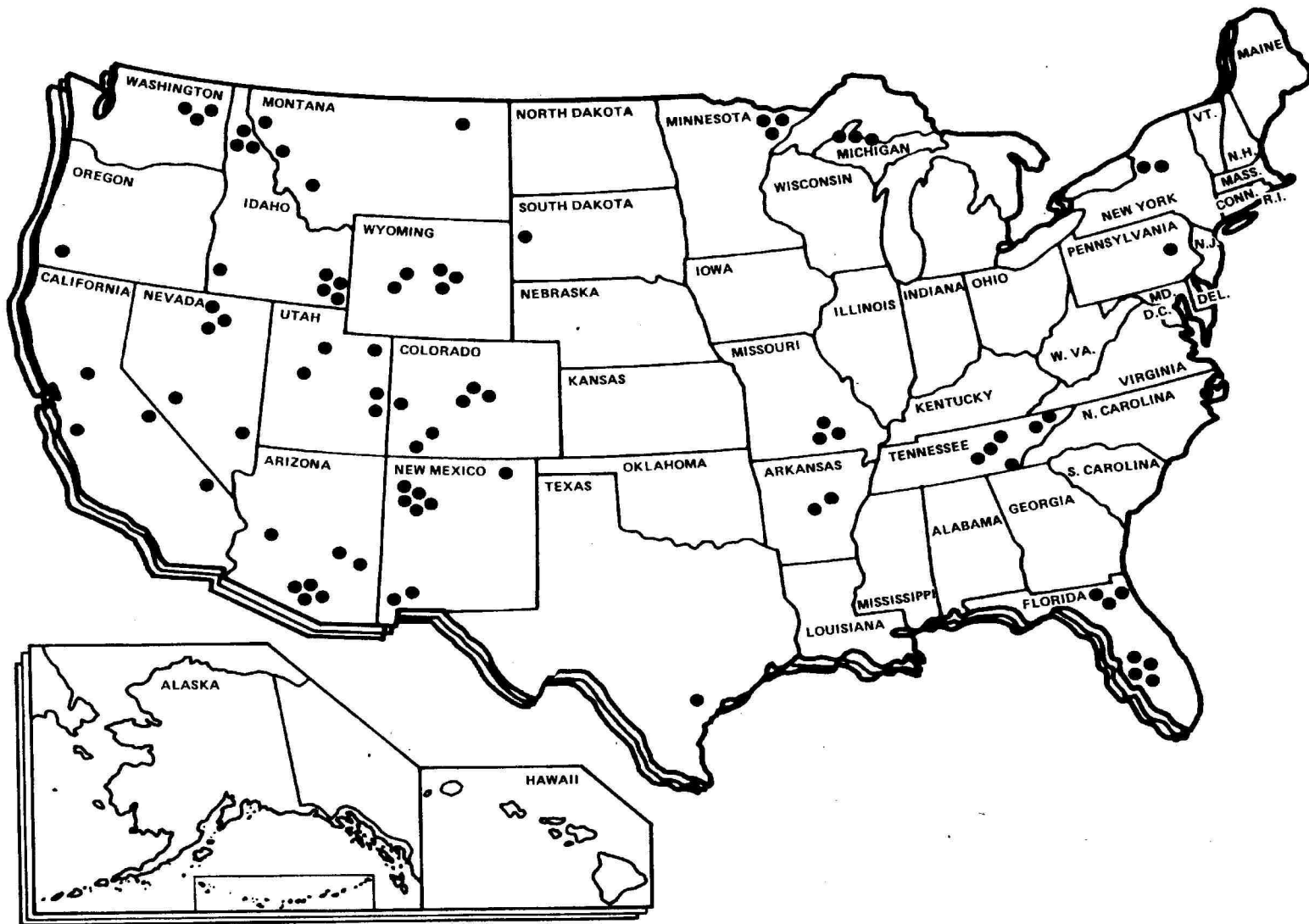


Figure 4-1. Approximate locations of mining/beneficiation sites active in 1980 sampled by EPA for this report

Mining wastes are far more likely to be corrosive or EP toxic than ignitable or reactive. Therefore, EPA did not evaluate ignitability, which measures the ability of wastes to cause or exacerbate fires, or reactivity, which measures explosivity and the ability of sulfide or cyanide containing wastes to generate toxic gases, vapors, or fumes, although some mining wastes containing cyanide or sulfide may be reactive. However, the toxic properties of cyanide-containing mining wastes were examined separately in this report.

The RCRA Subtitle C characteristics of corrosivity and EP toxicity are discussed below as they relate to mining and beneficiation wastes. In addition, copper dump leach, which may be a potential candidate for listing under 40 CFR 261.31 because of its potential EP toxicity and corrosivity, also is described.

4.1.1.1 Corrosivity

A waste is considered corrosive and therefore hazardous if it is a liquid and has a pH less than or equal to 2 or greater than or equal to 12.5, as determined by a pH meter.⁴ EPA chose pH as a "barometer of corrosivity, because wastes exhibiting low or high pH can cause harm to human tissue, promote the migration of toxic contaminants from other wastes, and harm aquatic life" (45 FR 33109, May 19, 1980). The lower pH limit of 2.0 was chosen so that "a number of substances generally thought to be innocuous and many industrial wastewaters prior to neutralization" would not fall within the corrosive classification. The upper pH limit of 12.5 was chosen to exclude lime-stabilized wastes and sludges from corrosive classification (45 FR 33109, May 19, 1980). For this study, EPA also evaluated whether samples had a high pH (greater than 10 but less than 12.5) or low pH (greater than 2 but less than 4), to aid in deciding which wastes could be potential candidates

for listing and which might cause damage to human health and the environment. These pH levels, and associated contamination by toxic metals, can degrade aquatic ecosystems.

Table 4-3 shows the results of the corrosivity analyses performed by EPA for this report. Of the 159 liquid waste samples taken by EPA, only 5 were corrosive. An additional 28 samples had low (more than 2 and less than 4) or high (more than 10 and less than 12.5) pH's. Some of the liquid samples, such as pregnant leach liquors or wastewater prior to treatment and discharge, are considered by industry to be process streams. The characteristics of some of these liquids would be likely to alter (improve) after the active life of the mine.

Table 4-4 identifies all of the industry segments that had at least one sample with a low or high pH. All copper dump leach operations had at least one sample with a pH less than or equal to 4 and 11 of the 23 liquid samples with pH's less than or equal to 4 were from the copper industry segment. Of the nine waste management operations having samples with pH's greater than 10, more than half were from tailings processed with caustic solutions. However, tailings such as these may later be treated to lower their pH, which reduces their hazard potential.

4.1.1.2 EP Toxicity

A solid waste is defined as EP toxic (and thus hazardous) if, using the test methods described in 40 CFR Part 261 (Appendix II), an extract from a representative sample of waste contains certain metals⁵ at a concentration greater than or equal to 100 times the maximum contaminant levels for these metals as established by EPA's National Interim Primary Drinking Water

Table 4-3 Results of Corrosivity Analyses of Liquid Mining Waste Sat

Mining industry segment	Number of samples analyzed	Number of samples with pH:				Number of samples corrosive ^a
		Less than or equal to 2 ^a	Between 2 and 4 ^a	Between 10 and 12.5 ^a	Greater than or equal to 12.5 ^a	
<u>Metals:</u>						
Copper	29	3 (10%) ^c	8 (29%)	3 (10%)	0	3 (10%)
Gold	5	0	0	1 (20%)	0	0
Iron	7	0	0	0	0	0
Lead	6	0	0	0	0	0
Molybdenum	9	0	1 (11%)	0	0	0
Silver	6	0	0	1 (17%)	0	0
Uranium	19	0	0	0	0	0
Zinc	15	0	0	0	0	0
Other metals ^b	47	1 (2%)	10 (21%)	4 (2%)	1 (2%)	2 (4%)
Subtotal	14	34 (3%)	19 (13%)	9 (6%)	1 (1%)	5 (3%)
<u>Nonmetals:</u>						
Asbestos	2	0	0	0	0	0
Phosphate	14	0	0	0	0	0
Subtotal	16	0	0	0	0	0
TOTAL	159	4 (3%)	19 (12%)	9 (6%)	1 (1%)	5 (3%)

a A waste is corrosive under current RCRA Subtitle C regulations if the pH is less than or than or equal to 12.5

b Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

c Numbers in parentheses are percentages of all samples analyzed for that industry segment that have the hazardous characteristic.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-4 Number of Mines, Wastes, and Operations with Samples Showing Low or High pH Levels

Number of waste management operations with at least one sample:

Mining industry segment	Type of waste management operation	Number of waste management operations analyzed		Having pH less than or equal to 2			Having pH between 2 and 4		Having pH between 10 and 12.5		Having pH greater than or equal to 12.5		Number of operations with corrosive waste ^a	
Copper	No. mines involved ^b	13		3		5		1		0		3		
	Mine waste ^c	7		0		3		0		0		0		
	Dump leach	6		3		3		0		0		3		
	Tailings	12		0		1		2		0		0		
Gold	No. mines involved	5		0		0		1		0		0		
	Mine waste	1		0		0		0		0		0		
	Heap leach	2		0		0		1		0		0		
	Tailings	2		0		0		1		0		0		
Molybdenum	No. mines involved	3		0		1		0		0		0		
	Mine waste	2		0		1		0		0		0		
	Tailings	3		0		0		0		0		0		
Silver	No. mines involved	5		0		0		1		0		0		
	Mine waste	0		0		0		0		0		0		
	Heap leach	0		0		0		0		0		0		
	Tailings	5		0		0		1		0		0		
Other metals ^d	No. mines involved	10		1		4		3		1		2		
	Mine waste	5		0		2		0		0		0		
	Dump/heap leach	1		0		0		1		0		0		
	Tailings	7		1		2		2		1		2		

Table 4-4 (continued)

Mining industry segment	Type of waste management operation	Number of waste management operations analyzed	<u>Number of waste management operations with</u>				of operations with corrosive waste ^a
			Having pH less than or equal to 2	Having pH between 2 and 4	Having pH between 10 and 12.5	Having pH greater than or equal to 12.5	
Total	No. mines involved	78	4	10	8	1	5
(All segments)	Mine waste	43	0	6	0	0	0
	Dump/Heap leach	10	3	3	1	0	3
	Tailings	52	1	3	7	1	2

a A waste is corrosive only if its pH is less than or equal to 2 or greater than or equal to 12.

b The number of mines involved may be less than the sum of sampled operations if one mine has more than one type of waste management operation. For example, the same mine site might have both mine waste and one or more leach operations.

c Mine waste includes mine water.

d Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Standards (NIPDWS) (40 CFR Part 141). EP toxic levels are:

- Mercury (Hg) >0.2 mg/l;
- . Cadmium (Cd) or selenium (Se) >1.0 mg/l;
- . Silver (Ag), arsenic (As), total chromium (Cr), or lead (Pb) >5.0 mg/l; and,
- . Barium (Ba) >100 mg/l.

EPA designed the EP toxicity test to simulate the leaching of hazardous constituents from a sanitary land fill into ground water. It approximates the conditions prevalent within a landfill where weak organic acids may come in contact with toxic metals. In recognition of the fact that contaminant concentration levels would decrease between the point at which the leachate migrates from the waste and the point of human or environmental exposure, EPA set EP toxicity levels for contaminants in leachate at 100 times the levels acceptable in drinking water. An attenuation factor of 100 was used rather than a lower level (e.g., 10 times the drinking water limit) because of the lack of empirical data on which to base an attenuation factor, the absence of a variance procedure (i.e., delisting) for wastes that fail the EP test, and because "EPA believes the...[extraction procedure] to be a somewhat less precise instrument than the listing mechanism for determining hazard, inasmuch as the EP fails to take into account factors such as the concentration of toxicants in the waste itself and the quantity of waste generated which would have a bearing on the hazardousness of the waste" (45 FR 33111, May 19, 1980). EPA preferred therefore to "entrust determinations of marginal hazard to the listing mechanism rather than to the EP" (45 FR 33111, May 19, 1980). In

adopting the 100-fold attenuation factor, the Agency explained that "anything which fails the EP at this factor has the potential to present a substantial hazard regardless of the attenuation mechanisms at play" (45 FR 33111, May 19, 1980).

The metals measured by RCRA's EP toxicity test can, however, cause some types of environmental damage at levels much lower than those that fail RCRA's EP toxicity test or even EPA's National Interim Primary Drinking Water Standards, especially if these metals are contained in wastes that contaminate surface water rather than ground water. Accordingly, the 24-hour average level of EP metals set by EPA's Ambient Water Quality Criteria for the Protection of Aquatic Life are, in all cases, lower than those permitted by EPA's drinking water standards, and therefore are much lower than the levels allowed by RCRA's EP toxicity test. This does not mean that all mining wastes meeting the EP toxicity test pose a threat to aquatic life, because the EP leaching procedure was designed to evaluate the potential of a given waste for unacceptable degradation of ground water and assumed that the wastes would be disposed of above an aquifer supplying drinking water (a conservative assumption). Table C-1 in Appendix C of this report provides a comparison of EP toxicity levels, drinking water levels, and ambient water quality levels for the metals measured by the EP toxicity test. Research findings on the levels of metals measured by the EP toxicity test (i.e., arsenic, cadmium, chromium, lead, mercury, and selenium) that are toxic to aquatic biota are summarized in Tables C-2 to C-7 of Appendix C.

EPA's sampling results indicate that a small percentage of the mining waste samples were EP toxic. Of the 332 samples from the metals mining

industry segments, 21 (6 percent) exhibited the characteristic of EP toxicity. These 21 samples were from the copper, gold, lead, silver, zinc, and other metals industry segments. An additional 39 samples had elevated levels (i.e., between 20 and 100 times the levels permitted by the drinking water standards) of the metals measured by the EP toxicity test; these additional samples came from these same industry segments and from the uranium and phosphate mining segments. These results are summarized in Table 4-5.

Tables 4-6 and 4-7 differentiate EP toxicity test results for solid samples and liquid samples, respectively. Twenty of the 21 EP toxic samples were solid samples and 31 of the 39 samples with elevated levels (i.e., between 20 and 100 times the levels permitted in the drinking water standards) of the metals measured by the EP toxicity test were solid samples. One liquid sample was EP toxic, and it was from the copper industry segment.

Table 4-8 identifies all industry segments that had at least one EP toxic sample or one sample with an elevated level of one of the metals measured by the EP toxicity test. Samples from 86 mines were tested for EP toxicity. At least one sample from 10 of these mines was EP toxic, and 29 mines had at least one sample with an elevated level (i.e. greater than 20 times the NIPDWS) of an EP toxic metal. A particularly high percentage of samples from gold heap leach and tailings, lead mine waste and tailings, zinc tailings, and copper dump leach operations had EP toxic or elevated levels of one of the metals measured by the EP toxicity test. Four of the eight copper dump leach operations, three of the seven zinc tailings operations, four of the six gold tailings operations, two of the three gold heap leach operations, and five of the six lead operations had at least one sample with a level of one of the metals measured by the EP toxicity test greater than or equal to 20 times the NIPDWS.

Table 4-5 Results of EP Toxicity Analyses for All Samples

Mining industry segment	Number of samples analyzed	Number of samples with at least one EP toxic metal at level between 20 and 100X the NIPDWS ^a	Number of samples EP toxic ^a
<u>Metals:</u>			
Copper	83	4 (15%)	1 (1%)
Gold	26	7 (27%)	3 (12%)
Iron	31	0	0
Lead	15	4 (27%)	6 (40%)
Molybdenum	15	0	0
Silver	25	3 (12%)	4 (16%)
Uranium	67	5 (7%)	0
Zinc	25	5 (20%)	4 (16%)
Other metals ^b	45	8 (18%)	3 (7%)
Subtotal	332	36 (11%)	21 (6%)
<u>Nonmetals:</u>			
Asbestos	7	0	0
Phosphate	70	3 (4%)	0
Subtotal	77	3	0
TOTAL	409	39 (10%)	21 (5%)

a Numbers in parentheses are percentages of all samples analyzed for that industry segment that had the hazardous characteristic.

b Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-6 Results of EP Toxicity Analyses for Solid Samples

Mining industry segment	Number of samples analyzed	Number of samples with at least one EP toxic metal at level between 20 and 100X the NIPDWS ^a	Number of samples EP toxic ^a
<u>Metals:</u>			
Copper	72	1 (1%)	0
Gold	22	4 (18%)	3 (14%)
Iron	30	0	0
Lead	14	4 (29%)	6 (43%)
Molybdenum	14	0	0
Silver	22	3 (14%)	4 (18%)
Uranium	63	5 (8%)	0
Zinc	22	5 (23%)	4 (18%)
Other metals ^b	39	6 (15%)	3 (8%)
Subtotal	298	28 (9%)	20 (7%)
<u>Nonmetals:</u>			
Asbestos	5	0	0
Phosphate	68	3 (4%)	0
Subtotal	73	3 (4%)	0
TOTAL	371	31 (8%)	20 (5%)

a Numbers in parentheses are percentages of all samples analyzed for that industry segment that had the hazardous characteristic.

b Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-7 Results of EP Toxicity Analyses for Liquid Samples

Mining industry segment	Number of samples analyzed	Number of samples with at least one EP toxic metal at level between 20 and 100X the NIPDWS ^a	Number of samples EP toxic ^a
<u>Metals:</u>			
Copper	11	3 (27%)	1 (9%)
Gold	4	3 (75%)	0
Iron	1	0	0
Lead	1	0	0
Molybdenum	1	0	0
Silver	3	0	0
Uranium	4	0	0
Zinc	3	0	0
Other metals ^a	6	2 (33%)	0
Subtotal	34	8 (24%)	1 (3%)
<u>Nonmetals:</u>			
Asbestos	2	0	0
Phosphate	2	0	0
Subtotal	4	0	0
TOTAL	38	8 (21%)	1 (3%)

a Numbers in parentheses are percentages of all samples analyzed for that industry segment that had the hazardous characteristic.

b Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: ERCO 1984 and Harry and Terlecky 1982.

Table 4-8 Number of Mines and Waste Management Operations with EP Toxic Sample or Samples Having Elevated Levels of Metals, as Measured by the EP Toxicity Test

Mining industry segment	Type of waste management operation	Number of operations analyzed	Number of operations with at least one EP toxic sample (100X NIPDWS)	Number of operations with at least one sample between 20 and 100X NIPDWS ^a	Number of operations with at least one sample greater than 20x the NIPDWS ^b
Copper	No. mines involved	13	1	3	4
	Mine waste	11	0	0	0
	Dump leach	8	1	3	4
	Tailings	13	0	0	0
Gold	No. mines involved	6	2	5	5
	Mine waste	6	1	0	1
	Heap leach	3	0	2	2
	Tailings	6	2	3	4
Lead	No. mines involved	4	3	2	3
	Mine waste	2	1	1	2
	Tailings	4	2	2	3
Phosphate	No. mines involved	13	0	3	3
	Mine waste	13	0	1	1
	Tailings	10	0	2	2
Silver	No. mines involved	6	1	2	2
	Mine waste	4	1	1	1
	Heap leach	0	0	0	0
	Tailings	6	1	1	2

Table 4-8 (continued)

Mining industry segment	Type of waste management operation	Number of operations analyzed	Number of operations with at least one EP toxic sample (100X NIPDWS)	Number of operations with at least one sample between 20 and 100X NIPDWS ^a	Number of operations with at least one sample greater than 20X the NIPDWS ^b
Uranium	No. mines involved	17	0	5	5
	Mine waste	17	0	5	5
	Tailings	NA	NA	NA	NA
Zinc	No. mines involved	7	2	3	3
	Mine waste	5	0	1	1
	Tailings	7	2	3	3
Other Metals ^c	No. mines involved	10	1	5	5
	Mine waste	7	1	2	2
	Tailings	9	1	3	4
TOTAL (All segments)	No. mines involved	86	10	28	29
	Mine waste	75	4	11	13
	Dump/Heap leach	11	1	5	6
	Tailings	65	8	14	18

NA indicates not applicable to this report.

a Samples were not EP toxic but had elevated levels of EP toxic metals.

b Samples were EP toxic or had elevated levels of EP toxic metals; results in this column may not equal the sum of results in the previous two columns because samples were often tested for more than one EP toxic metal.

c Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, t

tungsten and vanadium.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-9 shows the number and percentage of EP toxic samples and the number of samples having elevated levels of the metals measured by the EP toxicity test, by type of metal. Nineteen of the 21 samples failing the standard EP toxicity test failed because they had EP toxic levels of lead; in addition, 15 of the 39 samples with elevated levels of metals measured by the EP toxicity test had elevated levels of lead.

For purposes of comparison with these EP toxicity test results, most mine waste samples, most settled solid samples, and some low-grade ore samples were subjected to a modified EP toxicity test in which deionized water, rather than acetic acid, was used as the extracting medium. None of the 214 samples subjected to this test produced leachates containing metal concentrations at the EP toxic level, including the samples from the lead industry. These modified EP test results show that in at least some mining waste situations, lead and other toxic metal constituents may not be mobilized. Actual leachate samples were usually not obtained, and therefore actual leachate concentrations are unknown.

Since sulfuric acid simulates the situation in which waste leaches into an acidic environment more closely than does acetic acid, sulfuric acid might be an appropriate test leaching medium for modeling such an environment. For example, when lead combines with sulfuric acid, the lead sulfate that is formed precipitates out of the solution, which renders the lead less soluble than it

would be if it were combined with acetic acid. The results from EPA's modified EP toxicity test using deionized water, and information on the fate of some waste constituents in acidic environments, suggest that additional toxicity tests may be necessary to simulate the potential hazard posed by some mining wastes in some environments.

Table 4-9 Number and Percentage of EP Toxic Samples and Samples Having Elevated Levels of Metals Measured by the EP Toxicity Test, by Type of Metal

EP toxic metals	Number of samples EP toxic (100X NIPDWS) ^a	Percentage of all EP toxic samples ^a	Percentage of samples with elevated levels of EP toxic metals (greater than 20 and less than 100X NIPDWS) ^b	all samples with elevated levels of metals (greater than 20 and less than 100X NIPDWS) ^b
Arsenic	1	5	3	8
Barium	0	0	2	5
Cadmium	1	5	6	15
Chromium	0	0	3	8
Lead	19	86	15	38
Mercury	1	5	8	21
Silver	0	0	0	0
Selenium	0	0	6	15

a Twenty-one samples were EP toxic. However, one of these samples had EP toxic levels of two of the metals measured by the EP toxicity test.

b Thirty-nine samples contained metals measured by the EP toxicity test at levels between 20 and 100 times the NIPDWS. Many of these samples contained these levels for

more than one of the metal

Source: PEDCo Environmental Inc. 1984, ERCO 1984, Harty and Terlecky 1982.

4.1.1.3 EP Toxicity and Corrosivity (Copper Dump Leach Liquor)

In the case of dump leach liquor from copper dump leach operations, EPA believes that the results of the sampling and analyses performed on these samples and presented in Table 4-10 indicate that this waste may be a potential candidate for listing because of its acidity and relatively high concentrations of toxic metals. Partial results for samples of this waste were presented in Tables 4-3 and 4-4 (Results of Corrosivity Analyses) and Tables 4-5, 4-7, and 4-8 (Results of EP Toxicity Tests).

As shown in Table 4-10, the sample from leach operation no. 1 was EP toxic, with an arsenic level of 7.8 mg/l (156 times the NIPDWS) and a cadmium level of 1.8 mg/l (180 times the NIPDWS). Samples from all three leach operations had arsenic and cadmium levels at least 50 times their respective NIPDWS limits. Samples from two of the three operations had levels of chromium and selenium greater than 20 times the NIPDWS. Two of the three copper dump leach samples were corrosive, with pH's of less than 2, and the sample from the third site had a very low pH (2.49).

4.1.2 Other Characteristics

The other criteria used in this report to assess the potential hazard of mining waste include properties such as radioactivity and acid formation potential, and the presence at certain levels of hazardous constituents such as cyanide or asbestos. These constituents and properties are considered to be potentially hazardous because they are believed to pose a threat to human health and the environment if they are present in waste, including mining waste, at the levels specified below.

4.1.2.1 Cyanide

For the purpose of this report, EPA assessed liquid mining waste samples in relation to various cyanide levels: greater than or equal to 2 mg/l,

Table 4-10 Results of Corrosivity and EP Toxicity Analyses
of Copper Dump Leach Liquor Samples

Tested characteristic	Sample from leach operation no. 1 (rag/l)	Sample from leach operation no. 2 (rag/l)	Sample from leach operation no. 3 (mg/l)
pH	1.82	1.95	2.49
Arsenic mg/l (156 X NIPDWS ^a)	7.8 (70 X NIPDWS)	3.5 (50 X NIPDWS)	2.5
Barium mg/l	-- ^b	--	--
Cadmium mg/l (180 X NIPDWS)	1.8 (82 X NIPDWS)	0.82 (55 X NIPDWS)	0.55
Chromium mg/l (68 X NIPDWS)	3.4 (24 X NIPDWS)	1.2 (16 X NIPDWS)	0.81
Lead mg/l	--	--	--
Mercury mg/l	--	--	--
Selenium mg/l 157 X NIPDWS)	0.57 (35 X NIPDWS)	0.35	--
Silver mg/l	--	--	0.13 (3 X NIPDWS)

a National Interim Primary Drinking Water Standards.

b Dash (--) indicates level of this metal was less than the NIPDWS limit.

Source: ERCO 1984.

greater than or equal to 10 mg/l, and greater than or equal to 20 mg/l. These levels are 10, 50, and 100 times, respectively, the ambient water quality (AWQ) criterion for cyanide for the protection of human health (assuming daily ingestion of 2 liters of contaminated drinking water and 6.5 grams of tissue from organisms living in the same contaminated water). In the cost analysis section of this report, EPA used a cyanide level of greater than or equal to 10 mg/l to define the threshold of hazard. (No samples from the iron, uranium, other metals, asbestos, or phosphate industry segments were analyzed for cyanide, because cyanide is not introduced into mining and beneficiation processes in these industries.)

Because of the difficulty of analyzing waste samples for cyanide, EPA had several laboratories test several of the cyanide samples. Table 4-11 shows the results of cyanide analyses of liquid waste samples. Of 27 liquid samples analyzed for cyanide, 8 samples (30 percent) had at least one test result showing cyanide concentrations greater than or equal to 2.0 mg/l: seven of the samples were from the gold industry segment, and one sample was from the copper segment.

All of the cyanide sample test results for which at least one test showed a cyanide level greater than or equal to 2.0 mg/l are presented in Table 4-12. As shown on this table, the copper tailings pond sample had a cyanide level between 2 and 10 mg/l, and three of the five gold tailings pond samples had a cyanide level of at least 10 mg/l (and one of these three gold tailings samples had a cyanide level of at least 20 mg/l). Both samples from gold heap leach operations had cyanide levels greater than 10 mg/l.

EPA believes that wastes from gold and silver metal recovery and heap leach operations may be potential candidates for listing, because of their tendency to contain high levels of cyanide. Although EPA did not take any

Table 4-11 Results of Cyanide Analyses of Liquid Waste Samples

Mining industry segment	Number of samples analyzed	Number of samples with at least one test result showing CN greater than 2 mg/l a (10X AWQ)
<u>Metals:</u>		
Copper	13	1 (8)
Gold	7	7 (100)
Lead	3	0
Molybdenum	3	0
Zinc	1	0
TOTAL	27	8 (30)

a Numbers in parentheses are percentage of samples taken in that industry segment having the potentially hazardous characteristic.

Source: Personal Communication from PEDCo Environmental, Inc. 1984; ERCO 1984.

Table 4-12 Summary of Cyanide Sampling Results for Liquid Samples with at Least One Test Result Greater than 2 mg/l

Type of mine, operation, and sample identification	Number of tests	Number of tests with CN values less than 2 mg/l	Number of tests with CN values between 2 and 10 mg/l	Number of tests with CN values between 10 and 20 mg/l	Number of tests with CN values greater than or equal to 20 mg/l
Copper mine Tailings pond Sample A	1		1		
Gold mine 1 Tailings pond Sample A	3	1			
Sample B	4	2	3	1	
Gold mine 2 Tailings pond Sample A	4		3		1
Sample B	5				5
Gold mine 3 Tailings pond Sample A	1			1	
Gold mine 4 Barren leach pond Sample A	1				1
Gold mine 5 Pregnant heap leach Sample A	1			1	

Source: Personal communication from PEDCo Environmental, Inc. 1984; ERCO 1984.

samples of silver heap leach operations specifically, the similarity of gold and silver heap leach operations makes it likely that silver heap leach wastes also have high levels of cyanide. With few exceptions, gold and silver values that are leached are extracted from finely crushed ores, concentrates, tailings, and low-grade mine rock by dilute and weakly alkaline solutions of potassium cyanide or sodium cyanide.⁶

In analyses performed to support the promulgation of effluent limitations guidelines and standards for the ore mining and dressing point source category (i.e., metals mining and beneficiation), EPA's Effluent Guidelines Division (now the Industrial Technology Division) found that 2 of 68 mill wastewater samples tested for cyanide from the copper/lead/zinc/gold/silver/platinum/molybdenum industrial subcategory had cyanide levels greater than 2 mg/l but less than 10 mg/l⁷ But these were influent samples (to treatment) and would be treated prior to discharge. The highest discharge level, even without adequate treatment, was 0.4 mg of total cyanide per liter. Free cyanide was not measured.

Cyanide is an environmental hazard at levels significantly lower than 2 mg/l (EPA's Cyanide Ambient Water Quality Criteria for the protection of human health). The 24-hour average level of cyanide allowed by EPA's Ambient Water Quality Criteria for the protection of freshwater aquatic life is 0.0035 mg/l, with the concentration not to exceed 0.052 mg/l at any time (45 FR 79331; November 20, 1980). Table C-8 in Appendix C summarizes research findings on the toxicity of cyanide to aquatic biota.

4.1.2.2 Radioactivity

Naturally occurring radionuclides in mining waste and ore may pose a radiation hazard to human health if the waste is used in construction or land

reclamation or if concentrations of radionuclides (e.g., radium-226) are high enough to produce significant concentrations of hazardous decay products (e.g., radon-222).

Two criteria have been used in this report to assess potentially hazardous levels of radioactivity in mining waste. These criteria are both based on EPA's Standards for Protection Against Uranium Mill Tailings (40 CFR Part 192). These regulations contain a "cleanup" standard for uranium mill tailings that is set at a limit of 5 pCi of radium-226 per gram for the first 15 centimeters of soil below the surface. (The 5 pCi/g radioactivity criterion was also chosen by EPA in an Advance Notice of Proposed Rulemaking published in 1978 (43 FR 59022) that solicited comments on expanding the list of RCRA hazardous waste characteristics to include a "radioactivity characteristic".) The second radioactivity criterion used in this report, 20 pCi or more of radium-226, is based on the "disposal design" portion of the same standard, which requires that the average release rate of radon-222 not exceed 20 pCi per square meter per second. In this report, EPA made the conservative assumption that each picocurie of radium-226 per gram of waste produces an average release rate of 1 pCi of radon-222 per square meter per second. As a result, a radioactivity criterion of 20 pCi or more of radium-226 per gram of waste can be assumed to include all wastes that would fail to meet the radon-222 criterion set forth in 40 CFR Part 192.

EPA analyzed selected mining wastes to determine their radium-226 concentrations. Of 187 solid waste samples, 69 (37 percent) had radium-226 concentrations greater than or equal to 5 pCi/g. These samples were from the uranium, "other" metals, and phosphate mining segments. Of the same 187 samples, 34 (18 percent) had radium-226 concentrations greater than or equal

to 20 pCi/g; these samples were also from the uranium, other metals group, and phosphate mining industry segments. Results of the radium-226 analyses are presented in Table 4-13. (Asbestos samples were not tested for radioactivity, because EPA believed that wastes from this industry segment were unlikely to be radioactive.)

The number of mines and waste management operations having radioactive samples is presented in Table 4-14. All 17 uranium mines sampled by EPA had at least one mine waste sample with a level of radium-226 greater than or equal to 5 pCi/g. Fourteen of the 17 mines had at least one mine waste sample of radium-226 greater than or equal to 20 pCi/g. Ten of the 13 phosphate mines sampled by EPA had at least one sample with a level of radium-226 greater than or equal to 5 pCi/g. Only 2 of these mines, however, had samples with levels of radium-226 greater than or equal to 20 pCi/g. Two of the three other metals mines sampled had at least one sample with a level of radium-226 greater than or equal to 5 pCi/g. Only one of these mines, however, had a sample with a radium-226 level greater than or equal to 20 pCi/g.

Much of the available scientific literature concerned with radiation effects on organisms focuses on human health; information on these radiation effects is summarized in Table C-9 of Appendix C.

4.1.2.3 Asbestos

EPA chose to evaluate asbestos as a potentially hazardous mining waste constituent because of the well-documented inhalation danger that asbestos fibers, even in very small quantities, pose to human health. The health effects of asbestos exposure and the rationale for the level of asbestos considered in this report to be potentially hazardous are described below.

Table 4-13 Results of Radioactivity Analyses of Solid Waste Samples

Mining industry segment	Number of samples analyzed	Number of samples with Ra-226 level greater than or equal to 5 pCi/g ^b	Number of samples with Ra-226 levels greater than or equal to 20 pCi/g ^b
<u>Metals:</u>			
Copper	17	0	0
Gold	4	0	0
Iron	8	0	0
Lead	4	0	0
Molybdenum	6	0	0
Silver	6	0	0
Uranium	58	40 (69%)	29 (50%)
Zinc	10	0	0
Other metals ^a	7	5 (71%)	2 (29%)
Subtotal	120	45 (38%)	31 (26%)
<u>Nonmetals:</u>			
Phosphate	67	24 (36%)	3 (4%)
TOTAL	187	69 (37%)	34 (18%)

a Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

b Numbers in parentheses show percentage of samples taken in that industry segment having the potentially hazardous characteristic.

Sources: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-14 Number of Waste Management Operations
Having Radioactive Samples

Mining industry segment	Type of waste management operation	Number of operations with at least one sample	Number of operations with at least one sample	
		with level of Number of operations sampled	with level of Ra-226 greater than or equal to 5 pCi/g	Ra-226 greater than or equal to 20 pCi/g
Uranium	No. mines involved	17	17	14
	Mine waste	17	17	14
Phosphate	No. mines involved	13	10	2
	Mine waste	13	8	0
	Tailings	10	6	2
Other metals ^a	No. mines involved	3	2	1
	Mine waste	2	2	1
	Tailings	3	2	1
Total	No. mines involved	62	29	17
	Mine waste	55	27	15
	Heap/dump leach	2	0	0
	Tailings	41	8	3

a Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: PEDCo Environmental, Inc. 1984 and ERCO 1984.

According to the 1982 EPA Support Document for the Final Rule on Friable Asbestos-Containing Materials in School Buildings, "the hazards of asbestos exposure identified by epidemiologic research are cancers of the lung, pleura, peritoneum, larynx, pharynx and oral cavity, esophagus, stomach, colon and rectum, and kidney. Inhalation of asbestos fibers also produces a non-cancerous lung disease, asbestosis." Pleural and peritoneal mesotheliomas (cancers) are considered "signature" diseases for asbestos exposure; that is, these diseases are almost always caused by asbestos exposure. There are well-documented cases of mesotheliomas occurring in persons residing within a mile of an asbestos mine who had no other known asbestos exposure.⁸

EPA has promulgated a National Emission Standard for asbestos 140 CFR Part 61, Subpart M) under Section 112 of the Clean Air Act, establishing asbestos disposal requirements for active and inactive disposal sites. The regulation requires owners and operators of demolition and renovation projects to follow specific procedures to prevent asbestos emissions to the outside air, and further requires that demolition and renovation material be controlled if the material contains more than 1 percent asbestos by weight in a form that "hand pressure can crumble, pulverize, or reduce to powder when dry." In this report, the Agency used this 1 percent criterion to determine when mining wastes should be considered potentially hazardous on the basis of their asbestos content.

Only five waste samples obtained from asbestos mining and milling sites were analyzed for asbestos. The results of these analyses, shown in Table 4-15, indicate that the asbestos content of all of these samples greatly exceeded 1 percent.

Table 4-15 Results of Asbestos Analyses

Sample number	Type of asbestos	Estimated percentage asbestos by weight
1	Chrysotile	20-40
2	Chrysotile	5-20
3	Chrysotile	70-85
4	Chrysotile	30-50
5	Chrysotile	70-90

Source: Based on analyses performed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

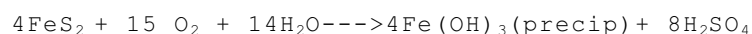
Regulations in Subpart M of 40 CFR Part 61 also contain standards for emissions from asbestos mills and active and inactive asbestos waste disposal sites. According to these regulations, owners and operators of asbestos mills must ensure that their facilities either discharge no visible emissions to the outside air, or use air cleaning devices to clean emissions as specified in 40 CFR 61.154. Owners and operators of active asbestos waste disposal sites must ensure that no visible asbestos emissions are discharged to the outside air, cover asbestos-containing waste material at least once a day, or receive approval from the Administrator of EPA to use alternate control measures. The regulation also requires security measures for active and inactive asbestos waste disposal sites.

There is evidence that asbestos is present in many of the wastes generated by the metals mining industry segments covered in this report. Asbestiform amphibole fibers from taconite mill tailings were detected at high concentrations (14-644 million fibers per liter) in Lake Superior.⁹ Sampling performed by EPA's Effluent Guidelines Division to develop effluent limitations guidelines and standards for the ore mining and dressing point source category showed that asbestos fibers were present in mine or mill water from almost all metals mining industry segments.¹⁰ Based on these results and on a statistical comparison with the suspended solids data, EPA found that by controlling the suspended solids in the discharge, the asbestiform fiber concentrations were effectively controlled in this industry.

Some effects of asbestos exposure, such as toxicity, bioaccumulation, cytotoxicity, asbestosis, and carcinogenicity on humans, bacteria, aquatic biota, and rats are summarized in Table C-10 in Appendix C.

4.1.2.4 Acid Formation Potential

The exposure and subsequent oxidation of naturally occurring metal sulfides (especially iron pyrite) in ores and mining waste can produce acid, which may increase the leaching and mobility of toxic waste constituents, including the heavy metals. Wastes that contain significant amounts of iron pyrites (FeS_2) or other base metal sulfides may release acids and metals for many decades. The hazard is initiated by the chemical reaction of air, water, pyrite, and pyrrhotite or other iron-bearing sulfides to produce sulfuric acid:



For example, the oxidation of the pyrite in 1 ton of waste having a 1 percent pyritic sulfur content would produce 15 kilograms of sulfuric acid. Unless the acid is neutralized (by the alkalinity of the water or by reaction with carbonate material in the waste), the acid will reduce the pH of the water and increase the concentration of the potentially toxic waste constituents, especially metals, that are leached and transported.

The potential effect of acid drainage on the concentration of metals in leachate is illustrated in Figure 4-2. For example, at a pH of 5.5, the free metal ion concentration in equilibrium with solid oxides or hydroxides of mercury (Hg) is approximately 0.0002 mg/l. If enough acid is added to the water to reduce the pH from 5.5 to 4.5, the concentration of mercury increases to more than 0.02 mg/l, an increase of more than two orders of magnitude. Although the diagram is an oversimplification and does not reflect the complexities of the real world, it does demonstrate that acid may greatly increase the concentration of metals in leachate and exacerbate environmental hazards.

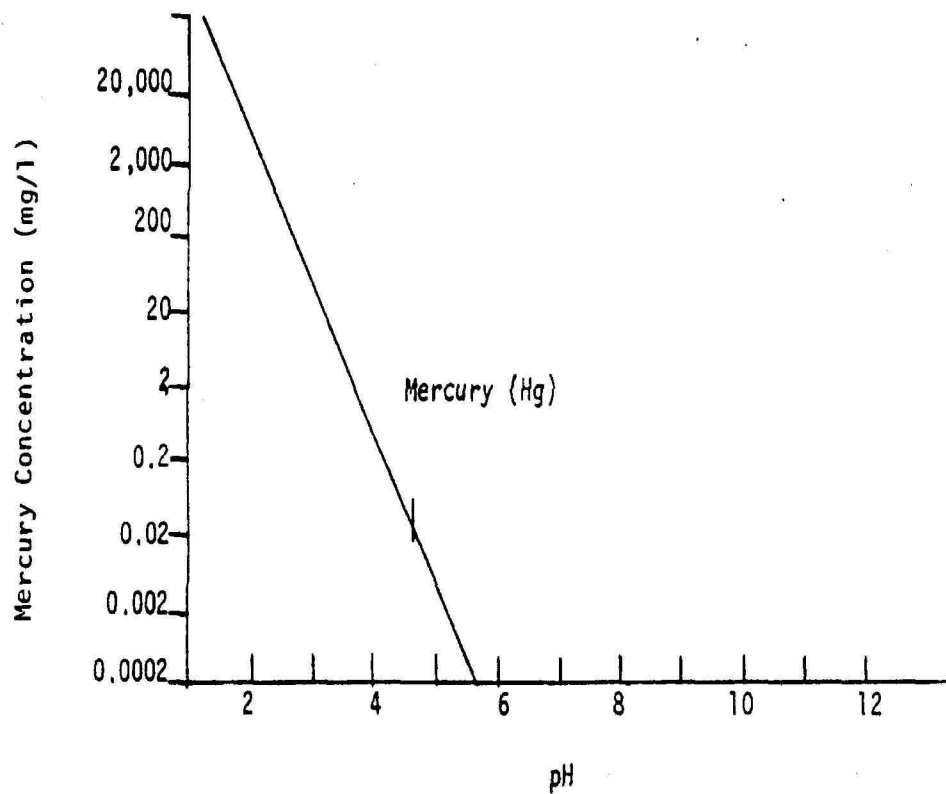


Figure 4-2 Free mercury ion concentrations in equilibrium with solid oxides or hydroxides

For this report, EPA estimated the quantity of metal mining waste that poses an acid drainage problem, using information on the mineral content of metal ores from 115 mines producing more than half of all the tailings generated by the metals mining industry segments represented in the U.S. Bureau of Mines Minerals Availability System data base.

To estimate whether the tailings from these mines have high, uncertain, or no acid formation potential, EPA made the following assumptions:

- If the data base reports that the minerals content of the ore in a particular mine includes pyrites and/or other metal sulfides but does not include carbonates, the tailings from that mine have a high potential for forming acid.

- If the data base reports that the minerals content of the ore in a particular mine includes pyrites and/or other metal sulfides and carbonates, the tailings from that mine have an uncertain potential for forming acid.

If the data base reports that the minerals content of the ore in a particular mine does not include pyrites and/or other metal sulfides,

the tailings from that mine have no potential for forming acid. The number of mines that generate tailings with high, uncertain, and no acid formation potential are presented, by industry segment, in Table 4-16.

According to Table 4-16, mines having the highest acid formation potential are found in the copper, gold, and silver industry segments.

The limitations of these data are:

- The data base does not report the mineral composition of the soil or rock that is removed at mines to gain access to an ore body. It was assumed that ore constituents were similar to waste (gangue)

Table 4-16 Estimated Acid Formation Potential of Tailings at Active Metal Mines by Industry Segment

Mining industry segment	Number of active mines for which minerals data exists	Number of mines with high acid formation potential ^{a,d}	Number of mines with uncertain acid formation potential ^{b,d}	Number of mine with no acid formation potential ^{c,d}
Copper	24	9 (38)	13 (54)	2 (8)
Gold	15	6 (40)	3 (20)	6 (40)
Iron	25	0	9 (36)	16 (64)
Lead	15	1 (7)	14 (93)	0
Silver	19	6 (31)	10 (53)	3 (16)
Zinc	18	0	17 (94)	1 (6)

a High Acid Formation Potential - Tailings derived from ores containing pyrites and/or other metal sulfides but no carbonate minerals (which would tend to neutralize produced acids).

b Uncertain Acid Formation Potential - Tailings derived from ores containing pyrites and/or other metal sulfides and carbonate minerals. (Such wastes may or may not produce acid, depending on the relative ratio of acid-forming to acid-neutralizing minerals.)

cNo Acid Formation Potential - Tailings from ores containing no pyrites or other metal sulfides.

d Numbers in parentheses are percentage of all mines in an industry segment.

Source:Derived from ore minerals information in U.S. Bureau of Mines Mineral Availability System data base. For this analysis, only mines active in 1982 were considered.

constituents, but it is not clear that this extrapolation could be extended from tailings to overburden. For example, the overburden may be completely different from the ore and have no acid formation potential.

- The reason that EPA categorized the acid formation potential of tailings from mines having both

acid-forming minerals (i.e., sulfides) and acid-neutralizing minerals (i.e., carbonates) as uncertain is that the actual acid formation potential of these tailings may range from high to none, depending on the relative concentrations of acid-forming and acid-neutralizing minerals in the tailings. The concentration processes at some mills require the addition of alkaline materials, which are mixed with the tailings and would reduce the acid formation potential of these high-sulfide, low-carbonate ores.

- The presence or absence of water, which is necessary for pyrite oxidation products to form acid, was not considered when categorizing the acid formation potential of these tailings, although many mines are located in arid regions of the country, where the lack of water reduces the potential for acid drainage. EPA has not considered whether chemical, mineralogical, biological, climatological, or physical factors might also influence the ability of tailings from particular mines to form acid.

Acid drainage can lower the pH of streams and other surface water. Table C-11 in Appendix C of this report provides a summary of the effects of decreased pH levels on fish.

4.2 ESTIMATED AMOUNTS OF POTENTIALLY HAZARDOUS MINING WASTE

EPA's methodology for estimating the amount of potentially hazardous mining waste is presented in Appendix B to this document. EPA's estimate of annual generation of hazardous waste and of the costs of treating and disposing of hazardous waste are based on projections of the number of mines, the amount of waste generated annually, and the amount of waste existing on site during 1985. EPA felt that a projection to 1985 was preferable to using historical data because of the rapid changes occurring in the mining industry in recent years (i.e., declining production in many segments).

Table 4-17 shows these estimates for eight mining industry segments: asbestos, copper, gold, lead, phosphate, silver, uranium, and zinc. Since there were no data on asbestos mines in EPA's data base, results for asbestos are based on historical data rather than projections; these data probably overestimate the number of active asbestos mines and the amount of waste generated at these mines annually, since EPA is aware that fewer than four asbestos mines are now in operation. EPA did not project results for the iron and molybdenum industry segments, because the wastes generated by these segments do not exhibit any of the hazard characteristics for which EPA tested. In addition, the other metals industry segments are not included in this analysis because of the small number of mines in these industry segments and the small amount of potentially hazardous waste generated at these mines annually.

As shown in Table 4-17, the copper industry segment generates the largest amount of waste annually: 632 million tons per year. The phosphate industry segment, generating 518 million tons of waste per year, has the second highest rate of annual waste generation. In many industry segments, the amount of waste existing on site is very large, exceeding the annual amount of waste generated by a factor of 20 to 40.

Table 4-17 Estimated Number of Active Mines, Annual Amount of Waste Generated, and Waste Existing on Site for 1985

Mining industry segment	Estimated number of active mines	Annual generation of waste (millions of metric tons)	Wastes existing on site (millions of metric tons) ^a
Asbestos ^b	4	5	NA
Copper	22	632	20,789
Gold	100	65	218
Lead	7	9	395
Phosphate	34	518	16,599
Silver	50	17	57
Uranium	50	91	1,564
Zinc	12	3	19

NA indicates data not available.

a Data extrapolated to industry segment based on estimates from Charles River Associates.

b Asbestos estimates developed by EPA.

Source: Adapted from Charles River Associates 1985c.

Table 4-18 presents EPA's estimates of the amount of mining wastes generated annually that exhibit the RCRA hazardous waste characteristics and mining wastes that may be potential candidates for listing, by industry segment. The estimated amount of corrosive waste generated annually is 50 million metric tons a year. All of this corrosive waste is generated by the copper industry segment. The estimated amount of EP toxic wastes generated annually is 11.2 million metric tons per year, and 63 percent of this EP toxic waste is generated by the gold industry segment. EP toxic waste is also generated by the lead, silver, and zinc industry segments.

Table 4-18 also shows the amount of wastes generated annually of the types that may be potential candidates for listing. The amount of copper dump leach waste (a potential candidate for listing because of low pH and elevated EP toxicity) generated annually is 182 million metric tons. Wastes from gold and silver metal recovery and heap leach operations may be potential candidates for listing because of their high levels of cyanide. The gold and silver industry segments generate 9.3 million metric tons of metal recovery wastes and 14 million metric tons of heap leach wastes annually that may be potential listing candidates. The gold industry generates larger amounts of these wastes annually than the silver industry.

Table 4-19 presents estimated annual generation amounts for wastes with hazardous characteristics that are particularly relevant to mining industry wastes: acid formation potential, radioactivity, and friable asbestos content. EPA estimates that 95 million metric tons of waste have a high potential for forming acid; all of this waste is generated in the copper industry segment. This estimate of waste having high acid formation potential is probably low, because EPA could only estimate the acid formation potential

Table 4-18 Estimated Amount of Waste with RCRA Characteristics Generated Annually and Mining Wastes That May be Potential Candidates for Listing

Mining industry segment	Amount of waste generated annually (million metric tons/yr)	RCRA characteristics			Potential candidates for listing		
		Corrosive waste (million metric tons/yr)	EP toxic waste (million metric tons/yr)	Copper dump leach wastes (million metric tons/yr)	Cyanide-treated gold and silver metal recovery wastes (million metric tons/yr)	Gold and silver heap leach wastes (million metric tons/yr)	
Asbestos	5	0	0	0	0	0	
Copper	632	50	0	182	0	0	
Gold	65	0	7	0	9	11	
Lead	9	0	2.9	0	0	0	
Phosphate	518	0	0	0	0	0	
Silver	17	0	1	0	0.3	3	
Uranium	91	0	0	0	0	0	
Zinc	3	0	0.3	0	0	0	
TOTAL	1,340	50	11.2	182	9.3	14	

Source: Derived by EPA from data in Charles River Associates 1985c, PEDCo Environmental, Inc. 1984, and ERCO 1984.

Table 4-19 Estimated Annual Amount of Waste Generated Exhibiting Other Potentially Hazardous Characteristics, By Industry Segment

Mining industry segment	Annual production of waste (million metric tons/year)	High acid formation potential (million metric tons/year)	Radium-226 greater than or equal to 5 pCi/g (million metric tons/year)	Radium-226 greater than or equal to 20 pCi/g (million metric tons/year)	Friable asbestos content greater than 1% by weight (million metric tons/year)
Asbestos	5	0	0	0	5
Copper	632	95	0	0	NA
Gold	65	0	0	0	NA
Lead	9	0	0	0	NA
Phosphate	518	0	352	13	NA
Silver	17	0	0	0	NA
Uranium	91	0	91	80	NA
Zinc	3	0	0	0	NA
TOTAL	1,340	95	443	93	5

NA indicates data not available.

Source: Derived by EPA from data in Charles River Associates 1985c, PEDCo Environmental, INC. 1984, and ERCO 1984.

of tailings (see Section 4.1.2.4). In addition, EPA classified the acid formation potential of many tailings piles as uncertain because of lack of data on the relative proportion of acid-forming to acid-neutralizing minerals in these tailings, even though some of them probably have a high potential for forming acid.

Table 4-19 presents estimates of radioactive waste at two radioactivity levels--radium-225 equal to or exceeding 5 pCi/g, and radium-226 equal to or exceeding 20 pCi/g. At the 5-pCi/g level, there are 443 million metric tons of radioactive waste generated annually, 352 million metric tons in the phosphate industry segment, and 91 million metric tons in the uranium industry segment. If the 5-pCi/g level is used as the hazard criterion, radioactive waste is the largest single contributor to the total amount of potentially hazardous waste generated by the industry segments of concern. At the 20-pCi/g level, 93 million metric tons of hazardous radioactive waste are generated annually: 13 million metric tons in the phosphate industry segment, and 80 million metric tons in the uranium industry segment.

The total amount of waste generated annually with a friable asbestos content of more than 1 percent by weight is 5 million metric tons per year. This amount may be an underestimate, because EPA did not sample wastes from industry segments other than the asbestos industry for their friable asbestos content.

Table 4-20 shows the estimated amount of potentially hazardous mining waste generated annually, by industry segment. If the radioactivity criterion used is 5 pCi or more of radium-226 per gram, 755.2 million metric tons of potentially hazardous mining waste are generated by these segments annually. If the radioactivity criterion chosen is 20 pCi or more of radium-226 per gram, 405.2 million metric tons of potentially hazardous mining waste are

Table 4-20 Total Amount of Potentially Hazardous Mining Waste Generated Annually

Mining industry segment	Annual production of waste (million metric tons/year)	Total amount of waste with RCRA characteristics (million metric tons/year) ^a	Total amount of potentially hazardous waste ^b (if Ra-226 is greater than or equal to 5 pCi) (million metric tons/year)	Total amount of potentially hazardous waste ^b (if Ra-226 is greater than or equal to 20 pCi) (million metric tons/year)
Asbestos	5	0	5	5
Copper	632	50	276	276
Gold	65	7	24	24
Lead	9	2.9	2.9	2.9
Phosphate	518	0	352	13
Silver	17	1	4	4
Uranium	91	0	91	80
Zinc	3	.3	.3	.3
TOTAL	1,340	61.2	755.2	405.2

a RCRA characteristic waste means corrosive or EP toxic waste.

b Total potentially hazardous waste means corrosive and EP toxic waste, waste containing cyanide at a level greater than 10 mg/l, radioactive waste, wastes containing friable asbestos content greater than 1 percent by weight, and waste with high acid formation potential.

Source: Derived by EPA from data in Charles River Associates 1985c, PEDCo Environment 1984, and ERCO 1984.

generated annually. These total estimates do not equal the sum of the amounts of waste considered hazardous based on individual hazard characteristics, because waste from a single operation may be classified as potentially hazardous for several different reasons. For example, 50 million metric tons of copper dump leach are corrosive; however, this waste is also included in the estimate of 182 million metric tons of copper dump leach waste that may be a potential candidate for listing.

Sixty-one million metric tons of mining industry waste are hazardous, according to the RCRA hazardous waste characteristics of corrosivity and EP toxicity; for comparison, the total amount of hazardous waste generated annually by all nonmining industry segments combined is 64 million metric tons. The portion of mining industry waste that is hazardous because it is EP toxic or corrosive is less than 5 percent of the total amount of waste generated by these industry segments. Of mining industry wastes that may be classified as hazardous because they are EP toxic or corrosive, 82 percent are from copper dump leach operations that generate corrosive wastes, and an additional 11 percent are EP toxic waste generated by the gold industry segment.

Wastes that are hazardous according to the RCRA hazardous waste characteristics of corrosivity and EP toxicity constitute 8 percent of the total amount of potentially hazardous mining waste generated annually, if the radioactivity hazard level chosen for radium-226 is equal to or more than 5 pCi/g. If the radioactivity hazard level for radium-226 is equal to or greater than 20 pCi/g, mining wastes that are hazardous according to the RCRA characteristics of corrosivity and EP toxicity comprise 15 percent of the total amount of potentially hazardous waste generated annually.

4.3 EFFECTIVENESS OF WASTE CONTAINMENT AT MINING WASTE SITES

Because a large amount of mining and beneficiation waste is potentially hazardous, human health and the environment could be adversely affected if these wastes escape containment. EPA commissioned a contractor study¹¹ to determine whether mining waste management facilities leak and, if they do, whether they release constituents of concern into surface or ground water.

The Agency also reviewed the results of other monitoring and mining studies to corroborate its findings.

4.3.1 EPA Study

EPA selected eight mining sites at which to monitor ground and surface water. The study focused on four types of waste (mine waste, tailings, dump leach waste, and mine water) and five mining industry segments (copper, gold, lead, uranium, and phosphate). Seven specific region-commodity categories of waste were monitored: Arizona copper tailings ponds, New Mexico copper dump leach wastes, gold tailings ponds from Nevada and South Dakota, Missouri lead tailings, New Mexico uranium mine water ponds, Idaho phosphate mine waste piles, and Florida phosphate tailings.

Ground water and surface water were monitored at four sites, ground water only at three sites, and surface water alone at one site. At each site, four or five samples were taken over a 6- to 9-month period. Samples were analyzed for selected indicators, properties, or compounds that might be evidence of leakage: antimony, arsenic, barium, beryllium, cadmium, calcium, chloride, chromium, copper, cyanide, fluoride, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, nitrate, phosphate, potassium, selenium, silver, sodium, sulfate, thallium, vanadium, zinc, acidity, alkalinity, conductivity, pH, radionuclides, settleable solids, suspended solids, total dissolved solids, total organic carbon, and turbidity.

Table 4-21 shows the Agency's interpretation of the monitoring results. These results indicate, with a reasonably high degree of confidence, that most of the facilities sampled do leak. However, the data do not demonstrate conclusively that constituents reach concentrations of concern at all sites or that they migrate over long distances.

At the copper mine sites, only ground water was monitored, because southwestern streams, in general, flow only after storms. The site at which copper tailings were monitored has surface runoff diversions for such events. This site also uses thickened discharge, recovers about 50 percent of its pond water, caps filled tailings ponds with alluvium, and then revegetates. Monitoring results showed chloride concentration gradients and an increase in total dissolved solids and sulfate over time in all wells, indicating seepage from the copper tailings pond. Concentrations of sulfate (four to six times higher than natural, local unimpacted levels) and total dissolved solids (two to four times higher than natural but within range for the aquifer) exceeded national drinking water standards in all wells and were even higher for the tailings pond. (Drinking water standards include the National Interim Primary Drinking Water Standards (NIPDWS) and National Secondary Drinking Water Standards. These standards are used as a basis for comparison.) Although the well farthest from the water table mound formed from pond seepage had the best water quality, concentrations of metals were very low (near detection limits) in all wells.

Copper dump leach liquor at the operation studied was very acidic, contained high levels of total dissolved solids, and exceeded nearly all primary and secondary drinking water standards. The pregnant leach liquor is collected in a leachate collection pond and pumped back to the precipitation

Table 4-21 Results of the Monitoring Program

Industry segment and management practice	Impact on		Seepage indicators	Comments
	Surface water	Ground water		
Copper tailings pond	NM ^a	yes	Sulfate, TDS, chloride	Low concentration of metals
Copper dump leach	NM	yes	Sulfate, TDS	Seepage is recharging the aquifer
Gold tailings pond	no	yes	Cyanide, chloride, sulfate, nickel, and ammonia	TDS, sulfate, and zinc concentrations in downgradient wells equivalent to concentrations in tailings pond water
Gold tailings pond	yes	yes	Cyanide, chloride, TDS, and pH	Surface water degradation after storms Cyanide not detected in surface water. Metals did not exceed drinking water standards, although several other indicators did
Lead tailings	no	no	Sulfate, TDS, chloride	Monitoring continues at this site; tailings may be having an effect on shallow ground water
Uranium mine water pond	NM	yes	Sulfate, chloride, TDS, and radionuclides	Barium, a precipitating agent, also found downgradient to pond
Phosphate overburden pile	no	NM		No observable impact
Phosphate sand and clay tailings	no	no	TDS, fluoride, chloride, total phosphorus, and total organic carbon	Seepage greater in shallower aquifer

a NM indicates not monitored.

Source: PEDCo Environmental, Inc. 1984

plant. At this site, ground-water degradation was evidenced by increased concentrations of calcium, sulfate, and total dissolved solids. The leach pile area is in an unlined natural drainage basin, and seepage from it apparently is recharging the aquifer. (Although a hydrogeologic study was not conducted to confirm that the mine pit acts as a ground-water sink, the bottom of the mine pit is 700 feet lower than the water level in the background well.)

Gold tailings ponds receive cyanidation process wastes, have high concentrations of cyanide, arsenic, cadmium, lead, mercury, and selenium, and are typically alkaline. Cyanide was not detected in surface water near either of the gold tailings ponds, although low but detectable cyanide levels in wells at both sites indicate seepage to ground water. At the first site, an underground mine, ore is crushed and then leached with a sodium cyanide solution. Significant downstream increases were found for fluoride, specific conductance, potassium, magnesium, sodium, and sulfate. These increases were thought to be caused largely by natural weathering processes, and the concentrations never exceeded South Dakota cold-water fish propagation stream standards. Alkalinity decreased downstream, and surface water was not considered to be impacted by the tailings pond. The strongest indicators of tailings pond water seepage into ground water are the presence of constituents added during the beneficiation process: chloride and cyanide. Cyanide was detected in three (of six) downgradient monitoring wells; chloride in two. Additionally, sulfate, sodium, nickel, and ammonia concentrations indicated seepage. Cadmium, manganese, iron, sulfate, and total dissolved solids were at or exceeded levels permitted by the drinking water standards. An independent analysis of these data concluded that concentrations of zinc, total dissolved solids, and sulfate in downgradient wells were essentially the same as concentrations in the tailings pond water,¹² supporting the conclusion that contaminants had migrated.

The second mine site in the gold mining industry also employs cyanide leaching. Spent leach liquors and leached ore are disposed of in tailings ponds; decant water is recycled to the mill. In surface water, concentrations of arsenic, manganese, total dissolved solids, and fluoride were significantly higher downstream than upstream, but cyanide was not detected. Tailings pond releases during storms and snowmelt were likely to be responsible for downstream water contamination. Ground-water monitoring revealed concentrations that exceeded drinking water standards for arsenic, manganese, pH, chloride, fluoride, nitrate, lead, manganese, and total dissolved solids. Seepage from abandoned underground mines may have contributed to these elevated levels, particularly for arsenic and manganese. Cyanide was detected at low levels in two of four wells, but metal concentrations did not exceed levels permitted in drinking water standards. The presence of cyanide and the increasing concentrations of total dissolved solids and chloride indicate tailings pond leakage.

The underground lead mine selected for the EPA study is in Missouri, where approximately 80 percent of all lead production occurs. The crushed ore goes through a froth flotation circuit, and tailings are pumped to a pond. This is a zero-discharge facility; a seepage and collection system recycles water to the milling system. Surface water monitoring indicated significant increases in calcium, magnesium, total dissolved solids, sulfate, nitrate, and chloride downstream. These increases were attributed to natural weathering processes, as all levels were within the range reported for streams that do not receive lead mining waste. Although small amounts of cyanide are used to process these ores, cyanide was not detected in surface water. The copper level exceeded the level specified in Missouri standard for the protection of

aquatic life both upstream and downstream from the tailings pond. Ground-water monitoring revealed high concentrations of sodium, fluoride, chloride, sulfate, and total dissolved solids; the latter three were considered evidence of seepage. In one sample, total dissolved solids exceeded permissible drinking water standard levels. Groundwater continues to be monitored at this site, which has a set of shallow and deep wells. Preliminary analysis indicates that tailings are having a greater impact on the water quality of the water in the shallower wells.

Only ground water was monitored near uranium mine water ponds in New Mexico. Uranium is recovered from surface and underground mining at this site. Waste management practices include overburden and waste piles, as well as unlined settling ponds. Permissible levels specified in drinking water standards were exceeded in several wells for selenium, nitrate, sulfate, manganese, and total dissolved solids. Elevated concentrations of magnesium, calcium, and sodium reflected the poor quality of the water in the aquifer. High levels of nitrate, magnesium, and total organic carbon may have resulted from leakage from a pond formerly used for sewage disposal. Gross beta and gross alpha concentrations were elevated, and measurable levels of radium-226 were also found. High concentrations of sulfate, chloride, total dissolved solids, and radionuclides in downgradient wells are considered indicators of pond seepage. Elevated downgradient levels of barium are another indication, because barium chloride is added to precipitate radium before water is discharged to the pond.

The impact of phosphate mine waste (overburden) was evaluated at a mine in eastern Idaho. This is an open-pit mining operation in which the overburden is generally backfilled to inactive mine sites. Waste rock is usually graded

and revegetated. Surface runoff is collected in basins to remove suspended solids before the water is discharged. EPA concluded, based on monitoring results, that current mining operations have little impact on surface water. Ground water was not monitored, because there were no suitable well sites.

In Florida, surface water and ground water were monitored near phosphate sand and clay tailings. Several waste management practices are used: the clay fractions are slurried to settling ponds and overflow is reused; sand tailings are used as backfill; overburden is piled or used in dike construction. Although levels of fluoride and sulfate were elevated in surface water, quality did not appear to be affected by the tailings. No monitored constituent exceeded its Florida Water Quality Standard. Two ground-water aquifers were monitored: a shallow water table aquifer and a deeper Floridian Aquifer. Elevated levels of several constituents in tailings serve as good indicators of seepage: sodium, sulfate, fluoride, total organic carbon, total phosphorus, radium-226, gross alpha, and gross beta. Of these, sodium, total organic carbon, fluoride, and total phosphorus were statistically higher in one or more wells downgradient to both aquifers than in respective background wells. Although the fluoride level exceeded that of the drinking water standards, all levels were within the range of ambient conditions. Chloride and total dissolved solids, however, were higher than ambient conditions, indicating that sand tailings constituents enter ground water. In conclusion, data indicate that neither clay slime ponds nor sand tailings have seriously affected the quality of shallow ground water. To date, neither practice has had an impact on the deeper Floridian Aquifer, but this aquifer may be recharged by the upper aquifer.

Table 4-22 compares selected concentrations of indicators in ground-water monitoring wells near the mine site with drinking water standards and water quality criteria, where these values are available. Ground-water degradation may be attributable to current and/or past mining practices, although naturally poor background water quality exists in some areas. Further degradation may occur if additional waste constituents (notably metals that have not thus far appeared in high concentrations in the monitoring wells) migrate in the future. Factors governing leaching rates, fate, and transport of constituents are complex, highly site specific, and dependent on physicochemical properties of both the waste and the local subsurface environment. For example, pH, reduction-oxidation potential, adsorption, coprecipitation processes, and complex chemical and hydrologic interactions are unique to each site. Seasonal factors that could not be assessed because of the time constraints of this study are other localized influences on constituent migration and transport. For these reasons, the results of this study cannot be directly extrapolated to industry segments employing similar waste management practices. Other studies may help place this monitoring study in perspective.

4.3.2 Other Studies

This review is not comprehensive, but provides conclusions from earlier EPA studies and studies conducted by state and local governments and the academic community.

Mines can contaminate ground water through waste disposal practices, but the nature of the contamination is highly variable and site specific.¹³ Copper waste management practices leak constituents into both surface and ground water. Factors that affect the migration of this leakage include ion

Table 4-22 Concentrations^a of Seepage Indicators in Ground Water at Selected Monitoring Sites^b

Constituent	Permissible level in drinking water standards ^c	Water quality criteria for aquatic life ^d	Gold tailings pond	Lead tailings	Uranium mine water ponds	Phosphate tailings
Chloride	250		1.94 - 58.4	22.8 - 44.8	26 - 210	55.3-63.2
Cyanide	0.02 - 0.2	0.0035	0.02 - 1.76			
Fluoride	1.4 - 2.4 ^e					1.85-6.58
Nickel		0.056 ^f	0.10 - 0.31			
Radium-226	5 pCi/l				0.25-.33 pCi/l	
Sulfate	250		800 - 1,200	38 - 108	770 - 1,810	
Total dissolved solids	500			269-556	1,650- 5,800	169-205

a Concentrations are in milligrams per liter except as otherwise indicated.

b Values are from one or more wells downgradient or upgradient (or both) from the site.

c National Interim Primary Drinking Water Standards (NIPDWS) or Secondary Drinking Water Standards, except for cyanide, where the "detection" limit is given.

d Values are for chronic freshwater animal toxicity.

e Temperature dependent.

f At a hardness of 50 mg/l CaCO₃.

Source: PEDCo Environmental, Inc. 1984

exchange capacity, hydraulic conductivity, and carbonate content.¹⁴

Carbonate neutralizes acids, and metals will precipitate when the pH is neutral or alkaline. A study of the Tucson mining district found that leakage from a copper tailings pond, indicated by hardness of and sulfate in the water, degraded ground water downgradient from the pond.¹⁵

The Globe-Miami area east of Phoenix was also the focus of a study.¹⁶ Copper mine runoff degraded surface water, and leaching practices degraded ground water by lowering the pH and increasing total dissolved solids, sulfate, copper, and other trace metal concentrations. Because of liquids leaching through the soil, alluvia in area washes are contaminated with sulfate, iron, and copper; the plume is advancing downgradient. Abandoned mines have the same potential; but because of the arid climate, significant degradation near these mines has not occurred.

The cyanidation process used in gold mining creates the potential for cyanide migration. Cyanide can be free, part of other compounds, or strongly complexed with metals. An EPA laboratory study¹⁷ showed that some forms are mobile, while others are less so. Movement depends on the type of cyanide and the media through which it travels. Potassium cyanide in leachate is less mobile than water containing cyanide ions in soils. High pH and low clay content increase cyanide mobility. In the soil, cyanide salts are biologically converted to nitrates or become complexed with metals. Without oxygen, cyanides become gaseous nitrogen compounds. These chemical changes take place when cyanide concentrations are low. Former mining practices that did not include wastewater treatment before release can be the source of persistent cyanide concentrations. One company, reopening a mine closed for nearly 40 years, found levels of cyanide far above detection limits (0.14-0.58 mg/l)

while drilling test wells before activities began.¹⁸ Before mitigative measures were implemented in 1982, one Nevada gold mine had ground-water levels as high as 5,509 mg/l.¹⁹

Before proper environmental treatment systems were in place, the Missouri Department of Conservation found a reduction in species diversity in the aquatic habitat in the lead mining district that was directly attributable to mining waste or milling effluent.²⁰ In another study, surface water in the area had low levels of dissolved metals, indicating potential transport out of the system. A downstream lake was thought to act as a sink, and some sediments had lead and zinc concentrations of 10 mg/l (Missouri Clean Water Commission effluent guidelines are 0.05 and 0.2 mg/l, respectively, for these metals). Releases from the sediments could create concentrations that exceed guideline levels, although little is known about the conditions under which these constituents may be released from the sediment.²¹

Radionuclide concentrations in uranium mine water are high, but a U.S. Department of the Interior study showed that these concentrations are reduced downstream as a result of adsorption or deposition in the soil.²² An earlier EPA study of the Grants Mineral Belt (New Mexico) estimated tailings pond seepage at 48.3 million gallons a year.²³

Idaho phosphate mining has been studied extensively. An earlier study at the EPA site (before current management practices were in place) indicated that mining practices had increased sediment and nutrients, added oils, and reduced the aquatic habitat.²⁴ Another study concluded that the potential existed for surface and subsurface flow patterns to be altered and for water quality to be degraded by several constituents: arsenic, cadmium, chromium, copper, lead, molybdenum, selenium, vanadium, zinc, uranium, radium-226,

nitrogen, and phosphorus. However, the high carbonate content reduces the solubility, and thus the potential impact, of these elements.²⁵ Finally, a recent USGS survey of the phosphate mining industry indicated that neither sand tailings nor clay slime ponds had a significant effect on ground-water quality.²⁶

4.4 STRUCTURAL INSTABILITY OF IMPOUNDMENTS

Impoundments may also pose threats to human health and the environment if they are not structurally stable. The structural failure of impoundments can release large volumes of waste. The causal factors in the failure of unstable waste structures and the subsequent flooding range from cloudbursts or minor earth tremors to extended periods of heavy rainfall, snow, or ice, or the dumping of more wastes than a saturated bank can contain.²⁷

Today there are thousands of tailings impoundments across the country that have varying degrees of structural stability. Many of these facilities are located in remote areas, but others are built within flood range of homes and well-traveled roads. If these structures fail, extensive surface water contamination, property damage, and life-threatening situations may occur.

Although dam and impoundment failures in the mining industry segments covered in this report have not yet caused human deaths in the United States, they have been responsible for significant environmental degradation. In Florida, for instance, the collapse of a phosphate railings dike in 1971 resulted in a massive fish kill and pollution of the Peace River over a distance of about 120 kilometers.²⁸ Other dam failures at metal mining sites have caused water quality degradation, crop failure, reductions in land values, and fish kills.²⁹

Stability problems are becoming more acute as the grade of the ore that is mined decreases (resulting in larger quantities of mine waste and tailings), as dam heights increase, and as the areas near mining facilities become more highly populated.³⁰ In addition, the recent promulgation of Effluent Limitations Guidelines and Standards for discharges to surface water may have aggravated these stability problems, because mine owners or operators may elect to comply with NPDES permits by impounding larger quantities of water than in the past. The potential danger posed by these impoundments is increased by the fact that many new, large mines are situated in mountainous areas where it is necessary to store large volumes of waste in valleys upstream of inhabited areas.³¹

The Mine Safety and Health Administration 's (MSHA's) recent "Report of Progress to Implement Federal Guidelines for Dam Safety" states that "experience has shown that the unregulated disposal of mine and mineral processing waste has the potential for disastrous consequences."³² According to the U.S. Department of Agriculture, an estimated 10-20 percent of the mine waste disposal embankments in the U.S. and Canada have experienced significant slope stability problems.³³

Technical personnel from MSHA recently completed field evaluations of 22 metal/nonmetal mine tailings dams located in areas under Bureau of Land Management leases. They determined that no dams were imminent hazards, but they did find technical deficiencies at many of the sites.³⁴ Investigations of mine tailings impounding structures (tailings dams) in the past 2 years, including five emergency calls requested by metal and nonmetal mine health and safety district managers, have revealed hazardous conditions. Most of the impounding structures inspected show some or most of these serious deficiencies: extremely steep downstream slopes; no emergency outlet

structures such as spillways or decant systems; high water, often up to the crest of the dams; cracks and sloughs in the structures themselves; narrow, uneven crests; the absence of trash racks to keep drainage pipes unclogged; and the absence of diverting ditches to keep surface runoff from entering impoundments.³⁵

4.5 DAMAGE CASES

EPA has compiled, reviewed, and analyzed data on National Priorities List (Superfund) mine and mill sites, data on damage at other mine and mill sites contained in state files,³⁶ and information in technical reports documenting cases of mine waste-related environmental contamination.^{37'38}

Although this analysis has separated the damage cases into four separate categories (damage at active, inactive, abandoned, and Superfund sites), it is important to note that active sites frequently become inactive, and inactive sites are sometimes abandoned. Therefore, some of the special environmental problems caused by conditions at inactive or abandoned sites (e.g., the erosion of tailings and their discharge into surface water, or the collection and discharge of frequently acidic and mineralized mine water) can only be avoided if active sites undergo some type of closure procedures before they become inactive or are abandoned.

4.5.1 Active Sites

Problems at active mine and mill sites have been documented in Arizona, Colorado, Florida, Missouri, Montana, and New Mexico; these sites represent phosphate, gold, silver, copper, uranium, and molybdenum operations. Releases ranged from catastrophic (loss of pond liner integrity, pond overflow, dam failure,⁴⁰ tailings pipeline break) to chronic (pond seepage). Contaminants included cyanides, sulfuric acid, and metals (copper, cadmium, chromium, lead,

mercury, and zinc). Both surface water⁴¹ and ground-water⁴² quality degradation have been observed, with impairment of aquatic ecosystems most commonly caused by massive releases. Remedial actions included relocating and improving pipelines, replacing liners, installing of leachate recovery systems, and stabilizing dams.

4.5.2 Inactive Sites

EPA has identified inactive mine and mill sites with environmental contamination in Arizona, California, Idaho, Missouri, Montana, and Utah. Mining industry segments represented include gold, silver, copper, mercury, lead, and zinc. Catastrophic releases, often associated with heavy rains, have resulted from dam failures, flood erosion of tailings, or dike washout. Several sites had intermittent or seasonal problems caused by snow melt or spring floods. Other sites, including old mine waste dumps and old tailings impoundments, had chronic seepage or runoff problems. Contaminants measured in surface water at concentrations greater than permissible levels in primary drinking water standards include arsenic, cadmium, and lead. Reductions in populations of fish and other freshwater organisms were observed near at least 12 inactive mine/mill sites that had had catastrophic or chronic releases. Mitigation measures included dam repair, pond lining, development of diversion ditches or secondary ponds, and lime treatment of tailings.⁴³

4.5.3 Abandoned Sites

Many of the waste disposal practices that have resulted in major incidents of environmental contamination at abandoned mine sites are no longer used (i.e., the dumping of tailings into streams or onto uncontained piles). EPA identified abandoned sites where environmental contamination resulted from such practices in Arizona, California, Idaho, Montana, and Vermont. Gold (placer and lode), silver, copper, lead, zinc, and unidentified hard rock

mining segments were represented. Various combinations of runoff, erosion, and seepage resulted in the release of arsenic, cadmium, cobalt, iron, manganese, lead, and zinc into surface waters, with resultant stress on stream ecosystems over stretches ranging from 2 to 80 kilometers.^{44,45} At some sites, diversion ditches and trenches to lower the water table have been used to mitigate these effects, but no mitigation has been attempted at most abandoned sites.

4.5.4 National Priorities List Sites

Environmental contamination problems at the 13 abandoned mine/mill sites on the Superfund National Priorities List (NPL) were generally caused by mine waste disposal practices that are no longer used. These sites are located in Arizona, California, Colorado, Idaho, Kansas, Oklahoma, and South Dakota. Mining industry segments represented are gold/silver (five sites), asbestos (three sites), lead/zinc (two sites), and copper (three sites). The three asbestos sites differ from the other sites in posing an airborne hazard to human health. The other 10 sites have chronic runoff and/or seepage, often with acidic mobilization and transport of arsenic, cadmium, copper, iron, lead, and/or zinc. Ground-water contamination, jeopardized water supplies, or potentially contaminated food chains are the effects common to most of these sites. Degradation of aquatic ecosystems also has been observed at nonasbestos NPL sites. Mitigative measures applied to date include pond sealing, installation of dams, berms, and diversion ditches, and use of the waste in construction. Additional measures will be taken following completion of the remedial plans for each site.

Brief descriptions of environmental contamination problems and threats to human health posed by five NPL sites follow.

1) Mountain View Mobile Home Estates is a 45-unit, 17-acre subdivision near the city of Globe in east-central Arizona. Before 1973, three mills, the Metate Asbestos Corporation, the Jaquays Asbestos Corporation, and the Globe town mill, processed chrysotile asbestos from nearby mines. In 1973 the Metate mill was found to be in violation of EPA air quality standards, and the Gila County Superior Court issued a temporary injunction to cease operations. The injunction was made permanent in May 1974. Before terminating operations, the owner of the Metate Corporation obtained a rezoning of this property into residential subdivisions. Approximately 115,000 cubic meters of asbestos mill tailings were used as the primary fill to level the site, which was then covered with topsoil. The mill buildings, housing, and equipment remained standing on the site. Lots were sold and occupied before the Superior Court injunction was made permanent.

In October, 1979, asbestos contamination of the soil and air was detected at the subdivision. Soil samples contained 5 to 50 percent asbestos fibers, and air samples had as many as 78 fibers/cm³. The asbestos in the soil and the airborne asbestos had contaminated all the households that were tested.

In December 1979, the Arizona Department of Health Services ordered the responsible asbestos companies to submit site cleanup plans to be implemented during the spring of 1980. In February 1980, the Arizona Division of Emergency Services, with the authorization of the governor, provided temporary housing for the residents (population approximately 130) while their properties were being decontaminated. The Metate mill was demolished, and open ground was capped with 6 inches of soil. The residents returned to their homes, but wind and water erosion exposed some of the asbestos landfill material on the surface of the soil, in the earth around the homes, and in two washes draining the site.

In April 1983, the Centers for Disease Control in Atlanta issued a health advisory for the site, noting continuing health hazards. The Remedial Investigation and Feasibility Study funded by EPA proposed three solutions to the problem.

The site abandonment option was chosen because it was the least costly of the three and eliminated the need for continued site monitoring and selection of an offsite disposal area. In addition to relocating the individuals in this community, it was necessary to demolish existing structures. In this particular case, mining waste contamination made the housing structures unfit for habitation and ruined the community.

2) Acid drainage discharging from numerous mines and dumps at the Iron Mountain site in California flows into Boulder Creek and Slickrock Creek, both tributaries of Spring Creek. Concentrations of cadmium, copper, iron, and zinc in the waters of these creeks exceed their respective permissible levels in Federal drinking water standards by factors of 2 to 5. Spring Creek, with its load of toxic metals, enters into the Sacramento River. The water supply intake for the city of Redding (population approximately 50,000) is 2 miles below the confluence of Spring Creek and the Sacramento River; and the water intake for Bella Vista Water District, which serves approximately 15,000 people, is located 1 mile farther downstream. Water samples taken at the Redding intake show elevated levels of cadmium, copper, iron, and zinc. Samples of fish tissue from resident trout collected in the Sacramento River showed high levels of cadmium, copper, and zinc.

3) At California Gulch, an NPL site in Colorado, approximately 30 private wells have been abandoned because water from these wells is unfit for human consumption. The surface water in California Gulch has been polluted so

extensively by acid mine drainage and the erosion of mining wastes into the stream from the nearby mine site that the stream is devoid of any aquatic life.

4) In 1962, the Celtor Chemical Works in Hoopa County, California, was abandoned by its owners/operators after they received numerous citations for contributing to pollution and fish kills in the Trinity River. Tailings ponds and piles located on the flood plain were the sources of contaminants. In 1964, 2 years after closure of the operation, a flood obliterated the structures and washed the tailings into the stream bed. As late as 1982, soil and sediment samples collected both on site and off site showed elevated and potentially health-threatening levels of cadmium (1.4 to 94.0 ppm), copper (140 to 2700 ppm), lead (6 to 1900 ppm), and arsenic (4.7 to 40 ppm).

5) The Anaconda complex of mining, milling, and smelting facilities in Montana disposed of approximately 5 billion tons of mining wastes in the Silver Bow Creek/Clark Fork River. For a stretch of approximately 180 kilometers, the river system was heavily damaged by tailings materials that were deposited in the river bed and in stream meanders. The river has recently begun to recover, and the beginning of a renewal in aquatic life can be seen in small plants and microinvertebrates that have become reestablished there. Although the waste disposal practices of the early to mid-1900s that caused this destruction are now prohibited by state and Federal laws; e.g., the Clean Water Act, the results of the waste practices of 40 years ago may take another 40 years, and a considerable amount of resources, to undo.

4.6 RISK ANALYSIS

As shown in the previous portions of this section, some wastes from mining and beneficiation do have the potential for being hazardous to human health and the environment. EPA's waste sampling and analysis indicate that some

mine waste and mill tailings are EP toxic, generally for lead. The sampling and analysis also showed that some leachates from copper leach dump operations have the characteristic of corrosivity, with a pH less than 2.0; and even those that are slightly less acidic can seriously jeopardize the quality of ground water. Other waste streams, although not hazardous under current RCRA characteristics, contain potentially hazardous concentrations of asbestos, cyanide, or radioactive isotopes. Some tailings have the potential for acid formation, and tailings impoundments may be subject to catastrophic breaks. Ground-water monitoring studies by EPA and other organizations have demonstrated that seepage from tailings impoundments into ground water is common. Finally, various degrees of damage have been caused by chronic or sudden releases from active, inactive, or abandoned mine and mill sites.

The previous portions of this section do not, however, provide quantitative estimates of releases, exposures, or risks associated with various mine and mill waste disposal practices. Without this information, the efficacy of current and alternative management practices cannot be compared. Therefore, EPA is now studying the use and release of cyanides and acids at typical mining and beneficiation operations. Specifically, cyanide releases from metal recovery circuits and heap leaching operations are being examined. Sulfuric acid releases being examined include those from active, inactive, and abandoned copper leach dumps and copper mill tailings impoundments.

EPA also has begun general studies relating the respective locations of drinking water supply systems and human population centers to mines and mills. A preliminary analysis, based on the Federal Reporting Data System, indicates that for 58 mine/mill sites, 20 have public ground-water systems within 5 kilometers of the site. These public water systems serve populations ranging from 42 to 47,494. Another EPA data base, the Graphic Exposure

Modeling System, uses Census Department data for population distributions and shows that people live within 5 kilometers of the mines at 30 of the 58 sites, with total populations between 5 and 11,736. Only 11 of the 58 sites have both resident populations and public ground-water systems within 5 kilometers.

If EPA identifies significant mining waste releases of cyanides, acids, or other constituents of concern, further analyses will focus on actual or potential risks to human populations or aquatic ecosystems. These studies will take into consideration the properties of various kinds of mine overburden, mill tailings, and heap/dump materials. Constituents other than EP toxic metals will be examined to determine whether their release can jeopardize aquatic organisms. Degradation, attenuation, precipitation, and other processes affecting the transport of released materials will be examined. To assess the potential for ground-water contamination, site-specific estimates will be made for such factors as porosity, permeability, and moisture content in the unsaturated zone, and for hydraulic conductivity in the saturated zone.

The risk analyses will be used to quantify threats that releases from mine and mill wastes pose to human health and the environment. These analyses will permit EPA to consider the wide variation in mining practices and settings, and to determine how changes in management practices can be implemented to improve and protect human health and the environment. EPA would conduct risk analysis as part of the development process for any major regulation of hazardous waste from the mining and beneficiation of ores and minerals.

4.7 SUMMARY

To identify mining and beneficiation wastes with the potential to endanger human health and the environment, EPA conducted an extensive program of sampling and analyzing mine waste, mill tailings, and wastes from heap and dump leach operations to determine their chemical properties. These studies were supplemented by data from ground-water monitoring, estimates of acid formation potential, a survey of state files to obtain documented cases of damage to human health and environment, and a review of the pertinent literature. In the sampling and analysis studies, corrosivity and EP toxicity were measured, because they are the RCRA Subtitle C characteristics most likely to be exhibited by wastes from mines, mills, and leach operations. The radioactive content of many solid and liquid samples also was measured. When appropriate, measurements were taken of asbestos or cyanide content. Most mine waste samples, most settled solid samples, and some low-grade ore samples were also subjected to a modified EP toxicity test, in which deionized water, rather than acetic acid, was used as the extracting medium. It should be noted that EPA has not yet performed quantitative assessments of the risks posed by mining wastes. These will require measurement or estimation of waste constituent transport, as well as receptor population exposure, dose, and response.

Extrapolating from the sampling and other analytic results, EPA estimated the amounts of potentially hazardous waste generated by the mining industry segments of concern annually. Estimated amounts are: 50 million metric tons a year (MMTY) of corrosive wastes; 11 MMTY of EP toxic wastes; 23 MMTY of cyanide-containing wastes; 95 MMTY of wastes with high acid formation potential; and 182 MMTY of copper leach dump wastes with the potential for releasing toxic metals and acidic (but not corrosive) liquids. If a

radioactivity level of 5 pCi per gram of waste is chosen as the radioactivity hazard criterion, 352 MMTY of phosphate mine waste and mill tailings and 91 MMTY of uranium overburden and low-grade ore would be considered hazardous. The total amount of potentially hazardous waste generated annually, 755 MMT, is not equal to the sum of the wastes in these categories because some of the wastes are in more than one category.

Analyses of ground water monitoring results and damage cases showed that a number of constituents leak from tailings impoundments and copper leach dump operations. However, it is not clear that this seepage constitutes a danger to human health, although it could degrade the quality of water in aquifers. The instability of impoundment dams was identified as a possible threat to human health and the environment, with damage at active, inactive, and abandoned sites attributed to catastrophic releases of impounded slimes, sands, and water.

In assessing the 13 mine/mill sites on the National Priorities List (NPL), prepared under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), EPA determined that the contamination problems associated with these sites were generally caused by disposal practices no longer used. Natural recovery and decontamination processes at these sites have been slow, and additional time and resources will be needed before recovery is complete.

To determine the degree of risk from wastes at existing mine, mill, and leaching operations, identified as hazardous or potentially hazardous, EPA is conducting studies on release rates, exposure pathways, and possible effects on human health and the environment. These risk assessments will permit EPA to consider the wide variability in mining wastes and environments and to determine which changes in management practices would be most beneficial.

SECTION 4 FOOTNOTES

- 1 PEDCo Environmental, Inc. 1984.
- 2 ERCO 1984.
- 3 Harty and Terlecky 1982.
- 4 Liquid wastes are also considered corrosive and therefore hazardous if they corrode steel at a rate greater than 6.35 mm per year at a test temperature of 55°C, as determined by the test method specified in National Association of Corrosion Engineers Standard TM-01-69, standardized in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods" or an equivalent test method approved by the Administrator (40 CFR 261.22). "EPA chose metal corrosion rate as its other barometer of corrosivity because wastes capable of corroding metal can escape from the containers in which they are segregated and liberate other wastes" (45 FR 33109, May 19, 1980). Because of the preliminary nature of the findings of this report, and because mining wastes are not likely to be stored in metal containers, EPA's corrosivity analyses for this report are based solely on the pH measure.
- 5 Wastes are also considered EP toxic (and thus hazardous) if the extract of a representative sample of waste contains any of the following pesticides or herbicides at levels specified in 40 CFR 261.24 (b), Table 1: Endrin; Lindane; Methoxychlor; Toxaphene; 2,4-D; 2,4,5-TP Silvex. EPA did not use the EP toxicity test to analyze mining wastes for these contaminants.
- 6 US EPA 1982a.
- 7 US EPA 1982a.
- 8 US EPA 1982b.
- 9 Cook et al. 1976.
- 10 US EPA 1982a.
- 11 PEDCo Environmental, Inc. 1984.
- 12 Williams and Steinhorst 1984.
- 13 US EPA 1977.
- 14 PEDCo Environmental, Inc. 1984.
- 15 Pima Association of Governments 1983.

16 Gordon 1984.
17 US EPA 1976.
18 Letter to Nevada Division of Environmental Protection from
Margaret Hills, Inc. 1981.
19 File memo from Cortez Gold Mines, Cortez, NV, 1983.
20 Ryck and Whitely 1974.
21 Jennett and Foil 1979.
22 U.S. Department of the Interior 1980.
23 US EPA 1977.
24 Platts and Hopson 1970.
25 Ralston et al. 1977.
26 U.S. Geological Survey, U.S. Bureau of Land Management, and
U.S. Forest Service, 1977.
27 Carroll 1983.
28 BOM 1981a.
29 SCS Engineers 1985.
30 Soderberg and Busch 1977.
31 Klohn 1981.
32 MSHA 1983.
33 USDA Forest Service 1979a.
34 MSHA 1983.
35 MSHA 1983.
36 The data from the state files and the National Priorities List
were not analyzed in depth, nor were any of the sites visited,
but enough documented cases were obtained to demonstrate the

range and severity of contamination problems that may be associated with mine and mill waste disposal.

37 SCS Engineers 1985.

4-74

38

Unites et al. 1985.

39

Martin and Mills 1976.

40

Schlick and Wahler 1976.

41

Missouri Geological Survey 1979.

42

Gordon 1984.

43

SCS Engineers 1984.

44

Schrader and Furbish 1978.

45

Jennett and Foil 1979.

4-75